Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-111

Proposal Title: Accelerating Biogas Production in Cold Climates

Project Manager Information

Name: Daniel Bond

Organization: U of MN - College of Biological Sciences

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Project Basic Information

Project Summary: This project will demonstrate that energy-rich biogas production from wastewater at cold temperatures could be possible using small solar-powered devices that directly aid microbial growth

Funds Requested: $399,000

Proposed Project Completion: June 30, 2026

LCCMR Funding Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

This proposal will test a new energy-saving technology that could speed up wastewater digestion in cold climates.

Hundreds of Minnesota treatment plants spend millions each year to inject oxygen into wastewater. This aerobic process supports rapid microbial growth, reducing treatment times to hours. While fast, it is expensive, and forfeits the bioenergy within the waste's sugars and oils.

Larger municipalities, such as Hennepin County and the Western Lake Superior Sanitary District, can afford million-gallon scale fermentation chambers, and the $4.4 M/y Minnesota Bioincentive Program aids construction of such facilities. These 'anaerobic digestors' do not require oxygen injection, and instead produce valuable methane-rich biogas. Unfortunately, growth under anaerobic conditions is very slow, requiring months to break down wastes in large reactors. Because of this, cities such as Duluth invest extra energy, burning most of their biogas to heat reactors and speed up digestion.

We propose a new approach that could rapidly produce valuable biogas without adding heat: building tiny devices that float in reactors, using free solar energy to stimulate organisms directly in the water. This technology could be especially useful at smaller scales, such as pre-treating concentrated food-processing wastes that can overwhelm local facilities.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

Our solution relies on a technology known as the 'microbial fuel cell'. Bacteria common in iron-rich Minnesota naturally link metal transformations to organic material breakdown. In other words, these bacteria eat rust. Electrodes can mimic these metals, encouraging rapid microbial growth while capturing their metabolic output as useful electricity.

However, adding microbial fuel cells to anaerobic digestors requires large electrodes, complex voltage regulators, membranes, and batteries. Smaller microbial fuel cells are used commercially, but only to treat agricultural wastes in warm climates.

Miniaturization now makes it possible to get the stimulating benefit of microbial fuel cells, without added complexity or heat. We can mass-produce glass particles the size of algae, that contain functional solar cells. Light creates a voltage across the particles, creating a favorable environment that stimulates microbial fuel cell bacteria. This internal boost causes biogas to be produced much faster than any available solution. No external power source, monitoring, membrane, or energy is needed, and the particles are large enough for easy recovery by gravity.

Our proposed work will collect the first measurements of biogas production by these simplified solar devices in unheated wastewater, and test their durability over multiple uses.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

We will measure biogas production during solar-enhanced bacterial breakdown of wastewater. This is a new energy-producing technology most relevant to northern climates as it could accelerate biogas production without complex electronics or added heat. In industries such as beverage and food processing, waste with a high organic content is common. Pre-treatment by our method could lower energy costs and reduce the burden on existing Minnesota waste treatment facilities.

Activities and Milestones

Activity 1: Test new solar particle designs for maximal microbial growth

Activity Budget: $159,600

Activity Description:
The first activity will identify optimal designs and produce useful quantities of robust solar cell particles.

The key to increasing performance is to identify the best conditions that stimulate the bacteria. We will measure growth of model microbes on particles powered by different sizes and numbers of solar cells. Preliminary experiments over the past two years suggest 1-2 panels per device, occupying about 25% of available space could be sufficient. We will then incubate samples of the best designs in reactors with decreasing amounts of illumination, with the goal of identifying the fastest gas production rates at <25% of normal sunlight intensity.

Following these experiments, our team will produce larger quantities of prototypes in three increasingly larger sizes. These will be used to test performance using model bacteria, testing which size is most easily recovered for reuse.

Activity Milestones:

Description	Completion Date
Design and test particle fabrication process	July 31, 2024
Screen prototypes on-chip with test organisms	December 31, 2024
Build free particle prototypes for tests with live bacteria	July 31, 2025

Activity 2: Identify high-performing solar particles with wastewater bacteria

Activity Budget: $239,400

Activity Description:
The second activity will focus on measuring biogas production by solar-powered particles using real anaerobic digestor bacteria, under cold conditions.

Every experiment will be compared to a non-illuminated control using the same bacteria. Experiments will begin by recovering bacteria from particles incubated with and without light reactors, and use rapid DNA sequencing to find which conditions successfully aid the desired microbial fuel cell bacteria. We will then incubate the best-performing particles while measuring biogas production, and conduct multiple cycles recovering and re-feeding particles to demonstrate reusability. Finally, we will conduct experiments with the best-performing designs at progressively colder temperatures, comparing gas production to standard anaerobic digestion.

Activity Milestones:

Description	Completion Date
Demonstrate naturally-occurring wastewater bacteria grow on particles	July 31, 2025
Compare cold temperature biogas production rates as a function of light and size	December 31, 2025
Compare biogas production rates of particles to anaerobic digestion at cold temperatures	June 30, 2026

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Joseph Talghader	University of Minnesota	Co-Investigator supervising design and fabrication of devices	Yes

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?

This project is designed to produce the first demonstration that, by simplifying the concept of the microbial fuel cell, energy recovery from wastewater can be accelerated dramatically. This will be of great interest to other engineers and researchers. If successful, we will pursue funding from the National Science Foundation and the Department of Energy to study how our invention could be scaled up and adapted for commercial use in other energy-intensive processes.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Microbes for Salt and Metal Removal	M.L. 2016, Chp. 186, Sec. 2, Subd. 04o	$596,000

Project Manager and Organization Qualifications

Project Manager Name: Daniel Bond

Job Title: Professor of Microbiology

Provide description of the project manager's qualifications to manage the proposed project.

The project manager has conducted research in water treatment, bioremediation, anaerobic digestion, and metal recovery for over 20 years. Since 2004, they have been a Professor of Microbiology and member of the BioTechnology Institute at the University of Minnesota. Relevant to this proposal, Dr. Bond was part of the original team that discovered bacteria could produce power using devices now known commercially as microbial fuel cells. Dr. Bond was project manager of a 2016 LCCMR project that focused on microbially-powered approaches for treating salt and metal contamination at the Soudan Iron Mine in Tower, MN.

Organization: U of MN - College of Biological Sciences

Organization Description:

This project is a collaboration between the Colleges of Biological Science and College of Science and Engineering at the University of Minnesota, one of the largest and most prestigious public universities in the United States. The laboratories directed by the project managers house all equipment needed to conduct the project and provide unique undergraduate educational experiences. The University of Minnesota also is home to the MN Nano Center, a world-class facility for nanoscale fabrication which will be used by University researchers "at cost".

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineli gible	% Bene fits	# FTE	Class ified Staff?	$ Amount
Personnel								
Daniel Bond		Project Manager			25%	0.15		$28,443
Joseph Talghader		Co-Investigator supervising micro fabrication			25%	0.15		$39,048
Graduate Students		Fabricate new devices and perform wastewater incubations			46%	2.49		$254,405
							Sub Total	**$321,896**
Contracts and Services								
Minnesota NanoFabrication Center	Internal services or fees (uncommon)	The MN NanoFabrication Center offers easy fee-for-service usage, removing the obstacles of capital equipment acquisition, maintenance costs, and long-term commitments. UMN faculty receive reduced academic use rates.				0		$33,615
							Sub Total	**$33,615**
Equipment, Tools, and Supplies								
	Tools and Supplies	Chemicals, molecular biology reagents, model reactors, and gas analysis supplies	To conduct experiments with prototype devices and collect data					$38,500
							Sub Total	**$38,500**
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								
							Sub Total	-

Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	Open access publication charges	Publishing results in 'open access' journals allows any member of the public and LCCMR staff to access and use data without any future library or subscription charges.					$4,989
							Sub Total	**$4,989**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$399,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
In-Kind	The University of Minnesota typically charges a 55% overhead rate for all research expenditures except for those on capital equipment and graduate student tuition. By law, the University of Minnesota does not charge this overhead on projects funded by the State of Minnesota.	Overhead	Secured	$174,019
			State Sub Total	**$174,019**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**$174,019**

Attachments

Required Attachments

Visual Component

File: bb43019f-d7c.pdf

Alternate Text for Visual Component

Overview of how solar energy delivered directly to bacteria could accelerate production of energy-rich gas from wastewater compared to standard anaerobic digestion...

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have potential for royalties, copyrights, patents, or sale of products and assets?

Yes

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

Yes

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

No

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Why do we need new water treatment options?

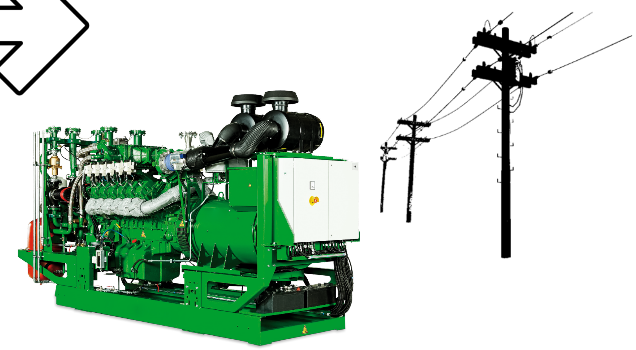
Waste treatment consumes significant electricity, and in northern states requires heating

If solar energy can be delivered *directly to microbes*, they will speed up their gas production

Small reusable solar cells that circulate *with the water* could provide this needed boost

Wastewater is often too concentrated to discharge to local treatment plant

New particles suspended in wastewater could use solar power to help bacteria more rapidly convert waste into gas without heating



Methane and hydrogen-rich biogas is used to generate electricity, while the remaining waste can be treated locally